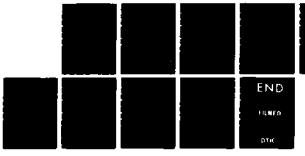
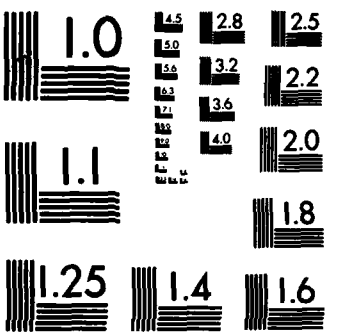
AD-A157 251 ROLE OF CHEMICAL BONDING IN ADHESION(U) AKRON UNIV OH 1/1
INST OF POLYMER SCIENCE A N GENT ET AL. JUN 85
N00014-76-C-0408

UNCLASSIFIED F/G 11/10 NL





OFFICE OF NAVAL RESEARCH

Contract N00014-76-C-0408

Project NR 092-555

Contract Title: ROLE OF CHEMICAL BONDING IN ADHESION

FINAL REPORT

Principal Investigators: A. N. Gent and P. Dreyfuss

Institute of Polymer Science
The University of Akron
Akron, Ohio 44325

ONR Scientific Officer: Dr. R. S. Miller
Office of Naval Research (Code 432)

June, 1985

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A157251
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Role of Chemical Bonding in Adhesion	5. TYPE OF REPORT & PERIOD COVERED Final Report: 3/77-10/84
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. N. Gent	8. CONTRACT OR GRANT NUMBER(s) N00014-76-C-0408
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Polymer Science, The University of Akron, Akron, Ohio 44325	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 092-555
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (Code 432), Power Program, Arlington, VA 22217	12. REPORT DATE June, 1985
	13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

According to attached distribution list.
Approved for public release; distribution unrestricted.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adhesion, Bonding, Composites, Elastomers, Inclusions, Rubber, Strength

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report lists and summarizes technical activities, reports, and publications completed during the period of the contract.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Role of Chemical Bonding in Adhesion: Final Report

1. Introduction

This project was concerned with the principal factors that govern the strength of elastomers when filled with rigid particles. The factors studied were: (i) the level of adhesion between the elastomer and the rigid surface; (ii) the size and number of the rigid inclusions; and, (iii) the strength of the elastomer itself. The main findings are outlined below and in 38 technical reports and publications, listed on pages 3-6. Additional keywords: Elastomeric composites; rubber;

2. Adhesion between elastomers and rigid surfaces.

The elastomers employed were polydimethylsiloxane, polybutadiene, ethylene-propylene copolymer (EPDM) and polyurethanes based on polybutadiene glycol. Substrate materials have included glass, aluminum, Mylar and various elastomers. Several specific modes of bonding have been detected in particular cases. In all cases, however, a direct correlation has been found between the mechanical strength of adhesion and the inferred degree of chemical interlinking between the two substances.

3. Effect of size, shape, and density of inclusions.

Small adhering sperical inclusions are not easily debonded. This experimental fact is supported by theoretical analysis also. However, failures were observed in the elastomeric binder near the bonded surface, and between two inclusions, when the local triaxial tension exceeded a critical level. A vacuole then appeared abruptly, and grew into a large propagating crack if the stresses were unbalanced in an appropriate way. This cavitation process is less serious with stiffer binders and with smaller inclusions, but it has not yet been thoroughly explored for highly-filled systems.

4. Strength of elastomeric materials.

Under severe conditions, notably at high temperatures and under sustained loads, and especially in the swollen state, the strength of crosslinked elastomers reaches a minimum level. This threshold value has been successfully measured for a wide variety of materials and shown to be in good agreement with a simple molecular theory. The threshold strength of any new elastomeric material, crosslinked to any degree, can

therefore now be predicted with some confidence. Behavior under other conditions has also been studied. At high rates of strain, inertia effects become important and the maximum rate of crack growth has been shown to be of the same order as the speed of sound in the elastomer. (This is found to be extremely high for highly-stretched elastomers, which become effectively much stiffer.) At low temperatures, when the elastomer becomes glass-hard, the strength becomes comparable to that of rigid plastics. And when the elastomer is capable of crystallization the strength becomes much greater than before, probably due to the plastic work expended in disrupting crystallites. Further work is needed to put this last aspect of "reinforcement" on a sound theoretical basis.

5. Conclusions

Major advances have been made in our understanding of failure processes in elastomeric materials themselves, in elastomeric composites containing spherical or fibrous rigid inclusions, and at the interface between an elastomeric material and a rigid material. In the course of this work new test methods for measuring the strength of adhesion have also been developed.

Technical Reports and Publications

1. M.L. Runge and P. Dreyfuss, September, 1977, "Adhesion of Elastomers to Rigid Substrates - Three Substrates with Unexpectedly High Adhesion", J. Appl. Polym. Sci., 23, 1863-1866(1979).

2. M.L. Runge and P. Dreyfuss, September, 1977, "Effect of Interfacial Chemical Bonding on the Strength of Adhesion of Glass-Polybutadiene Joints", J. Polym. Sci.: Polym. Chem. Ed., 17, 1067-1072(1979).

3. P. Dreyfuss, July, 1978, "Chemistry of Silane Coupling Reactions I. Reaction of Trimethylmethoxysilane and Triethylsilanol Studied by Gas Liquid Chromatography", Macromolecules, 11, 1031-1036(1978).

4. P. Dreyfuss, L.J. Fetters and A.N. Gent, July, 1978, "Chemistry of Silane Coupling Reactions II. Reaction of Dimethylmethoxysilanated Poly(Butadiene) with Triethylsilanol and with Glass", Macromolecules, 11, 1036-1038(1978).

5. R.J. Chang, A.N. Gent, C.C. Hsu and K.C. Sehgal, October, 1979, "Bonding Elastomer Layers Together by a Surface Oxidation Reaction", J. Appl. Polymer Sci., 25, 163-171(1980).

6. P. Dreyfuss, Y. Eckstein, Q.S. Lien and H.H. Dollwet, December, 1979, "Effect of Number of Chemical Bonds on the Strength of Adhesion Between Glass and Polybutadiene", J. Polym. Sci.: Polym. Lett. Ed., 19, 427-433(1981).

7. P. Dreyfuss, A.N. Gent and J.R. Williams, April, 1980, "Tear Strength and Tensile Strength of Model Filled Elastomers", J. Polym. Sci.: Polym. Phys. Ed., 18, 2135-2142(1980).

8. A.N. Gent, July, 1980, "Detachment of an Elastic Matrix from a Rigid Spherical Inclusion", J. Materials Sci., 15, 2884-2888(1980).

9. R.-J. Chang and A.N. Gent, January, 1981, "Effect of Interfacial Bonding on the Strength of Adhesion of Elastomers I. Self-Adhesion", J. Polym. Sci.: Polym. Phys. Ed., 19, 1619-1633(1981).

10. R.-J. Chang and A.N. Gent, February, 1981, "Effect of Interfacial Bonding on the Strength of Adhesion of Elastomers II. Dissimilar Adherends", J. Polym. Sci.: Polym. Phys. Ed., 19, 1635-1640(1981).

11. A.N. Gent, April, 1981, "The Role of Chemical Bonding in the Adhesion of Elastomers", Int. J. Adhesion and Adhesives, 1, 175-180(1981); Rubber Chem. Technol., 55, 525-535(1982).

12. A.N. Gent and R.H. Tobias, April, 1981, "Threshold Tear Strength of Some Molecular Networks", pp. 367-376 in "Elastomers and Rubber Elasticity", ed. by J.E. Mark and J. Lal, A.C.S. Symposium Series 193, American Chemical Society, Washington, D.C., 1982.

13. Y. Eckstein and P. Dreyfuss, September, 1981, "Effect of Glass Filler Size on Tensile Properties and Tear Strength of Polybutadiene", J. Polym. Sci.: Polym. Phys. Ed., 20, 49-63(1982).

14. A.N. Gent and O.H. Yeoh, October, 1981, "Failure Loads for Model Adhesive Joints Subjected to Tension, Compression or Torsion", J. Materials Sci., 17, 1713-1722(1982).

15. A.N. Gent and R.H. Tobias, April, 1982, "Threshold Tear Strength of Elastomers", J. Polym. Sci.: Polym. Phys. Ed., 20, 2051-2058(1982).

16. A.N. Gent and P. Marteny, May, 1982, "The Effect of Strain Upon the Velocity of Sound and The Velocity of Free Retraction for Natural Rubber", J. Appl. Phys., 53, 6069-6075(1982).

17. A.N. Gent and P. Marteny, May, 1982, "Crack Velocities in Natural Rubber", J. Materials Sci., 17, 2955-2960(1982).

18. A.N. Gent and P. Vondracek, September, 1982, "Spontaneous Adhesion of Silicone Rubber", J. Appl. Polym. Sci., 27, 4357-4364(1982).

19. P. Vondracek and A.N. Gent, September, 1982, "Slow Decomposition of Silicone Rubber", J. Appl. Polym. Sci., 27, 4517-4523(1982).

20. A.N. Gent and R.H. Tobias, October, 1982, "Diffusion and Equilibrium Swelling of Macromolecular Networks by Their Linear Homologs", J. Polym. Sci.: Polym. Phys. Ed., 20, 2317-2327(1982).

21. P. Dreyfuss and Y. Eckstein, October, 1982, "Effect of Size of Nonreinforcing Fillers on Mechanical Properties of Elastomers", I.E.C. Prod. Res. and Dev., 22, 71-77(1983).

22. Y. Eckstein and P. Dreyfuss, October, 1982, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates I. Reactions of Amines During Peroxide Curing of Polybutadiene", J. Adhesion, 13, 303-313 (1982).

23. Y. Eckstein and P. Dreyfuss, October, 1982, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates. II. Reactions of Amines with Triethylsilanol and/or Fumed Silica", J. Adhesion, 15, 163-178(1983).

24. Y. Eckstein and P. Dreyfuss, October, 1983, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates. III. Effect of Amines on the Reaction of Peroxide with Olefinic Groups", J. Adhesion, 15, 179-192(1983).

25. P. Dreyfuss and Y. Eckstein, October, 1983, "Role of Amines in Adhesion of Polybutadiene to Glass Substrates. IV. The Effect of Amine Structure and Concentration on the Strength of Adhesion", J. Adhesion, 15, 193-202(1983).

26. R.P. Burford, April, 1983, "Fracture Toughness of Polybutadiene at Cryogenic Temperatures", J. Materials Science, 18, 3756-3764 (1983).

27. A.K. Bhowmick, A.N. Gent and C.T.R. Pulford, April, 1983, "Tear Strength of Elastomers under Threshold Conditions", Rubb. Chem. Technol., 56, 226-232(1983).

28. A.N. Gent, April, 1983, "Fracture Mechanics Applied to Elastomeric Composites", Rubb. Chem. Technol., 56, 1011-1018(1983).

29. A.N. Gent and B. Park, September, 1983, "Failure Processes in Elastomers at or near a Rigid Spherical Inclusion", J. Materials Science, 19, 1947-1956(1984).

29A. F. Liang and P. Dreyfuss, December, 1983, "Effect of Amine Surface Treatment on the Adhesion of a Polyurethane to the Surface", Organic Coating and Applied Polym. Sci. Proceedings, 48, 18-22 (1983), "Adhesive Chemistry - Developments and Trends", L.-H. Lee, Ed., Plenum Press.

30. A.N. Gent and R.H. Tobias, February, 1984, "Effect of Interfacial Bonding on the Strength of Adhesion of Elastomers III. Interlinking by Molecular Entanglements", J. Polym. Sci.: Polym. Phys. Ed., 22, 1483-1490(1984).

31. F. Liang and P. Dreyfuss, February, 1984, "Durability of Adhesive Bonds Between Glass or Metal Substrates and a Polybutadiene-Polyurethane", J. Appl. Polym. Sci., in press(1985).

32. A.N. Gent and C.T.R. Pulford, February, 1984, "Micromechanics of Fracture in Elastomers", J. Materials Science, 19, 3612-3619(1984).

33. A.N. Gent and W.R. Rodgers, September, 1984, "Mechanochemical Reactions of Elastomers with Metals", J. Polymer Sci.: Polymer Chem. Ed., 23, 829-841(1985).

34. M.D. Ellul and A.N. Gent, September, 1984, "The Role of Molecular Diffusion in the Adhesion of Elastomers", J. Polymer Sci.: Polymer Phys. Ed., 22, 1953-1968(1984).

35. M.D. Ellul and A.N. Gent, March, 1985, "The Role of Molecular Diffusion in the Adhesion of EPDM and EPR Elastomers", J. Polymer Sci.: Polymer Phys. Ed., in press (1985).

36. A.N. Gent and Jongkoo Jeong, March, 1985, "Plastic Deformation of Crystalline Polymers", Polymer Engineering and Science, in press (1985).

37. K. Cho and A.N. Gent, March 1985, "An Improved Torsional Method for Determining the Fracture Toughness of Stiff Materials and Adhesive Joints", Internatl. J. Fracture, in press (1985).

Personnel

Faculty: Alan N. Gent, Principal Investigator

Post-Doctoral Fellows and Research Associates:

P. Dreyfuss, Co-Principal Investigator

A.K. Bhowmick, Post-Doctoral Fellow

R.P. Burford, Visiting Scientist from University of New South Wales, Sydney, Australia

Y. Eckstein, Post-Doctoral Fellow

F. Liang, Visiting Scientist from Chinese Rubber Research Institute, China

Q.S. Lien, Post-Doctoral Fellow

M.L. Runge, Post-Doctoral Fellow

K.C. Sehgal, Post-Doctoral Fellow

P. Vondracek, Visiting Scientist from Macromolecular Research Institute, Prague, Czechoslovakia

O.H. Yeoh, Visiting Scientist from Malaysian Rubber Research Institute, Kuala Lumpur, Malaysia

Ph.D. Students (date awarded):

R.-J. Chang(1980)

K. Cho

N.K. Eib

M.D. Ellul(1984)

J. Jeong(1985)

P. Marteny(1982)

B. Park(1983)

C.T.R. Pulford(1978)

W.R. Rodgers(1984)

R.H. Tobias(1983)

M.S. Students (date awarded):

C.C. Hsu(1979)

J. Jeong(1983)

G.S. Rogowski(1984)

Undergraduate Students:

C. Slezak

J.R. Williams

(DYN)

DISTRIBUTION LIST

Dr. R.S. Miller
Office of Naval Research
Code 432P
Arlington, VA 22217
(10 copies)

Dr. L.V. Schmidt
Office of Naval Technology
Code 07CT
Arlington, VA 22217

Dr. J. Pastine
Naval Sea Systems Command
Code 06R
Washington, DC 20362

JHU Applied Physics Laboratory
ATTN: CPIA (Mr. T.W. Christian)
Johns Hopkins Rd.
Laurel, MD 20707

Dr. Kenneth D. Hartman
Hercules Aerospace Division
Hercules Incorporated
Alleghany Ballistic Lab
P.O. Box 210
Washington, DC 21502

Dr. R. McGuire
Lawrence Livermore Laboratory
University of California
Code L-324
Livermore, CA 94550

Mr. Otto K. Heiney
AFATL-DLJG
Elgin AFB, FL 32542

P.A. Miller
736 Leavenworth Street, #6
San Francisco, CA 94109

Dr. Merrill K. King
Atlantic Research Corp.
5390 Cherokee Avenue
Alexandria, VA 22312

Dr. W. Moniz
Naval Research Lab.
Code 6120
Washington, DC 20375

Dr. R.L. Lou
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramenta, CA 95813

Dr. K.F. Mueller
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

Dr. R. Olsen
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Prof. M. Nicol
Dept. of Chemistry & Biochemistry
University of California
Los Angeles, CA 90024

Mr. L. Roslund
Naval Surface Weapons Center
Code R10C
White Oak, Silver Spring, MD 20910

Dr. Randy Peters
Aerojet Strategic Propulsion Co.
Bldg. 05025 - Dept 5400 - MS 167
P.O. Box 15699C
Sacramento, CA 95813

Dr. David C. Sayles
Ballistic Missile Defense
Advanced Technology Center
P.O. Box 1500
Huntsville, AL 35807

Dr. D. Mann
U.S. Army Research Office
Engineering Division
Box 12211
Research Triangle Park, NC 27709-2211

(DYN)

DISTRIBUTION LIST

Mr. R. Geisler
ATTN: DY/MS-24
AFRPL
Edwards AFB, CA 93523

Naval Air Systems Command
ATTN: Mr. Bertram P. Sobers
NAVAIR-320G
Jefferson Plaza 1, RM 472
Washington, DC 20361

R.B. Steele
Aerojet Strategic Propulsion Co.
P.O. Box 15699C
Sacramento, CA 95813

Mr. M. Stosz
Naval Surface Weapons Center
Code R10B
White Oak
Silver Spring, MD 20910

Mr. E.S. Sutton
Thiokol Corporation
Elkton Division
P.O. Box 241
Elkton, MD 21921

Dr. Grant Thompson
Morton Thiokol, Inc.
Wasatch Division
MS 240 P.O. Box 524
Brigham City, UT 84302

Dr. R.S. Valentini
United Technologies Chemical Systems
P.O. Box 50015
San Jose, CA 95150-0015

Dr. R.F. Walker
Chief, Energetic Materials Division
DRSMC-LCE (D), B-3022
USA ARDC
Dover, NJ 07801

Dr. Janet Wall
Code 012
Director, Research Administration
Naval Postgraduate School
Monterey, CA 93943

Director
US Army Ballistic Research Lab.
ATTN: DRXBR-IBD
Aberdeen Proving Ground, MD 21005

Commander
US Army Missile Command
ATTN: DRSMI-RKL
Walter W. Wharton
Redstone Arsenal, AL 35898

Dr. Ingo W. May
Army Ballistic Research Lab.
ARRADCOM
Code DRXBR - 1BD
Aberdeen Proving Ground, MD 21005

Dr. E. Zimet
Office of Naval Technology
Code 071
Arlington, VA 22217

Dr. Ronald L. Derr
Naval Weapons Center
Code 389
China Lake, CA 93555

T. Boggs
Naval Weapons Center
Code 389
China Lake, CA 93555

Lee C. Estabrook, P.E.
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, Louisiana 71130

Dr. J.R. West
Morton Thiokol, Inc.
P.O. Box 30058
Shreveport, Louisiana 71130

Dr. D.D. Dillehay
Morton Thiokol, Inc.
Longhorn Division
Marshall, TX 75670

G.T. Bowman
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

(DYN)

DISTRIBUTION LIST

R.E. Shenton
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mike Barnes
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Dr. Lionel Dickinson
Naval Explosive Ordinance
Disposal Tech. Center
Code D
Indian Head, MD 20340

Prof. J.T. Dickinson
Washington State University
Dept. of Physics 4
Pullman, WA 99164-2814

M.H. Miles
Dept. of Physics
Washington State University
Pullman, WA 99164-2814

Dr. T.F. Davidson
Vice President, Technical
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, Illinois 60606

Mr. J. Consaga
Naval Surface Weapons Center
Code R-16
Indian Head, MD 20640

Naval Sea Systems Command
ATTN: Mr. Charles M. Christensen
NAVSEA-62R2
Crystal Plaza, Bldg. 6, Rm 806
Washington, DC 20362

Mr. R. Beauregard
Naval Sea Systems Command
SEA 64E
Washington, DC 20362

Brian Wheatley
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

Mr. G. Edwards
Naval Sea Systems Command
Code 62R32
Washington, DC 20362

C. Dickinson
Naval Surface Weapons Center
White Oak, Code R-13
Silver Spring, MD 20910

Prof. John Deutch
MIT
Department of Chemistry
Cambridge, MA 02139

Dr. E.H. deButts
Hercules Aerospace Co.
P.O. Box 27408
Salt Lake City, UT 84127

David A. Flanigan
Director, Advanced Technology
Morton Thiokol, Inc.
Aerospace Group
110 North Wacker Drive
Chicago, Illinois 60606

Dr. L.H. Caveny
Air Force Office of Scientific
Research
Directorate of Aerospace Sciences
Bolling Air Force Base
Washington, DC 20332

W.G. Roger
Code 5253
Naval Ordance Station
Indian Head, MD 20640

Dr. Donald L. Ball
Air Force Office of Scientific
Research
Directorate of Chemical &
Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

(DYN)

DISTRIBUTION LIST

Dr. Anthony J. Matuszko
Air Force Office of Scientific Research
Directorate of Chemical & Atmospheric Sciences
Bolling Air Force Base
Washington, DC 20332

Dr. H.G. Adolph
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

Dr. Michael Chaykovsky
Naval Surface Weapons Center
Code R11
White Oak
Silver Spring, MD 20910

U.S. Army Research Office
Chemical & Biological Sciences Division
P.O. Box 12211
Research Triangle Park, NC 27709

J.J. Rocchio
USA Ballistic Research Lab.
Aberdeen Proving Ground, MD 21005-5066

G. Butcher
Hercules, Inc.
MS X2H
P.O. Box 98
Magna, Utah 84044

G.A. Zimmerman
Aerojet Tactical Systems
P.O. Box 13400
Sacramento, CA 95813

W. Waesche
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

B. Swanson
INC-4 MS C-346
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Dr. James T. Bryant
Naval Weapons Center
Code 3205B
China Lake, CA 93555

Dr. John S. Wilkes, Jr.
FJSRL/NC
USAF Academy, CO 80840

Dr. L. Rothstein
Assistant Director
Naval Explosives Dev. Engineering Dept.
Naval Weapons Station
Yorktown, VA 23691

Dr. H. Rosenwasser
AIR-320R
Naval Air Systems Command
Washington, DC 20361

Dr. M.J. Kamlet
Naval Surface Weapons Center
Code R11
White Oak, Silver Spring, MD 2091C

Dr. Joyce J. Kaufman
The Johns Hopkins University
Department of Chemistry
Baltimore, MD 21218

Dr. Henry Webster, III
Manager, Chemical Sciences Branch
ATTN: Code 5063
Crane, IN 47522

Dr. A. Nielsen
Naval Weapons Center
Code 385
China Lake, CA 93555

Dr. A.L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, DC 20380

(DYN)

DISTRIBUTION LIST

K.D. Pae
High Pressure Materials Research Lab.
Rutgers University
P.O. Box 909
Piscataway, NJ 08854

Dr. John K. Dienes
T-3, B216
Los Alamos National Lab.
P.O. Box 1663
Los Alamos, NM 87544

A.N. Gent
Institute Polymer Science
University of Akron
Akron, OH 44325

Dr. D.A. Shockey
SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025

Dr. R.B. Kruse
Morton Thiokol, Inc.
Huntsville Division
Huntsville, AL 35807-7501

G. Butcher
Hercules, Inc.
P.O. Box 98
Magna, UT 84044

repeat

W. Waesche
Atlantic Research Corp.
7511 Wellington Road
Gainesville, VA 22065

repeat

Dr. R. Bernecker
Naval Surface Weapons Center
Code R13
White Oak
Silver Spring, MD 20910

Prof. Edward Price
Georgia Institute of Tech.
School of Aerospace Engineering
Atlanta, GA 30332

J.A. Birkett
Naval Ordnance Station
Code 5253K
Indian Head, MD 20640

Prof. R.W. Armstrong
University of Maryland
Dept. of Mechanical Engineering
College Park, MD 20742

Herb Richter
Code 385
Naval Weapons Center
China Lake, CA 93555

J.T. Rosenberg
SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025

G.A. Zimmerman
Aeroject Tactical Systems
P.O. Box 13400
Sacramento, CA 95813

repeat

Prof. Kenneth Kuo
Pennsylvania State University
Dept. of Mechanical Engineering
University Park, PA 16802

T.L. Boggs
Naval Weapons Center
Code 3891
China Lake, CA 93555

(DYN)

DISTRIBUTION LIST

Dr. C.S. Coffey
Naval Surface Weapons Center
Code R13
White Oak
Silver Spring, MD 20910

D. Curran
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

E.L. Throckmorton
Code SP-2731
Strategic Systems Program Office
Crystal Mall #3, RM 1048
Washington, DC 23076

Dr. R. Martinson
Lockheed Missiles and Space Co.
Research and Development
3251 Hanover Street
Palo Alto, CA 94304

C. Gotzmer
Naval Surface Weapons Center
Code R-11
White Oak
Silver Spring, MD 20910

G.A. Lo
3251 Hanover Street
B204 Lockheed Palo Alto Research Lab
Palto Alto, CA 94304

R.A. Schapery
Civil Engineering Department
Texas A&M University
College Station, TX 77843

J.M. Culver
Strategic Systems Projects Office
SSPO/SP-2731
Crystal Mall #3, RM 1048
Washington, DC 20376

Prof. G.D. Duvall
Washington State University
Department of Physics
Pullman, WA 99163

Dr. E. Martin
Naval Weapons Center
Code 3858
China Lake, CA 93555

Dr. M. Farber
135 W. Maple Avenue
Monnovia, CA 91016

W.L. Elban
Naval Surface Weapons Center
White Oak, Bldg. 343
Silver Spring, MD 20910

G.E. Manser
Morton Thiokol
Wasatch Division
P.O. Box 524
Brigham City, UT 84302

R.G. Rosemeier
Brimrose Corporation
7720 Belair Road
Baltimore, MD 20742

Ser 432/84/340
Revised January 1985

Administrative Contracting
Officer (see contract for
address)
(1 copy)

Director
Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375
(6 copies)

Defense Technical Information Center
Bldg. 5, Cameron Station
Alexandria, VA 22314
(12 copies)

Dr. Robert Polvani
National Bureau of Standards
Metallurgy Division
Washington, D.C. 20234

Dr. Y. Gupta
Washington State University
Department of Physics
Pullman, WA 99163

END

FILMED

9-85

DTIC